

The COSINUS project - a NaI-based cryogenic calorimeter for direct dark matter detection

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Abstract. At present the results in the field of direct dark matter search are in tension: the positive claim of DAMA/LIBRA versus null results from other experiments. However, the comparison of the results of different experiments involves model dependencies, in particular because of the different target materials in use. The COSINUS R&D project aims to operate NaI as a cryogenic calorimeter. Such a detector would not only allow for a direct comparison to DAMA/LIBRA, but would also provide a low(er) nuclear recoil threshold and particle discrimination.

Today, the existence of dark matter (DM) is certain, its underlying nature, however, is still largely unknown. At present, the DAMA/LIBRA experiment¹ claims to observe dark matter via its expected annual modulation [1], which disagrees with null results from many other direct DM searches (fig. 3, [2]). Stating disagreement, however, only holds for certain assumption on the interaction mechanism of DM with Standard Model particles. The major model-dependence in the comparison of experiments comes from the use of different target materials: DAMA uses NaI(Tl), while the excluding null results are obtained with Ar, CaWO₄, CsI, Ge, Si and Xe targets.

The R&D project COSINUS² aims to develop a NaI-based cryogenic detector [3] offering particle discrimination and, as also using NaI, its results can be directly compared to DAMA.

The heart of a COSINUS detector is an undoped NaI crystal, cooled to mK temperatures. Any particle interaction in the crystal will excite phonons. Recording this phonon signal with a so-called transition edge sensor (TES) provides a very precise measurement of the energy deposited in the crystal, quasi independent of the type of interacting particle. In addition, also scintillation light is produced by a particle interaction which we measure by pairing the NaI crystal with a cryogenic light detector, read-out with a second TES³. Since the amount of

¹ DAMA/LIBRA will be shortened to DAMA in the following.

² Cryogenic Observatory for Signals seen in Next-generation Underground Searches

³ The TESs are produced by the Max-Planck-Institute of Physics in Munich.

produced scintillation light strongly depends on the interacting particle, measuring phonons and light provides particle identification. In particular, it allows to discriminate e^-/γ -events from nuclear recoils; the former being the main background, the latter being believed (in the vast majority of models) to be induced by DM.

Fig. 1 depicts the detector design. Since the hygroscopic nature of NaI (blue) and its low melting point prevents a direct evaporation of the TES, we instead evaporate it on a carrier crystal (purple).⁴ The light detector is a silicon beaker (black) completely surrounding the target crystal. The beaker shape offers two attractive features: Firstly, it maximizes light collection and secondly it avoids - in combination with the carrier crystal exceeding the diameter of the beaker - any line of sight between the target crystal and non-active surfaces. Such a geometry is mandatory to veto any α -induced surface backgrounds [4].

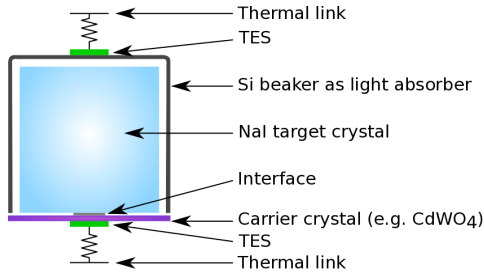


Figure 1. Schematic of a COSINUS detector.

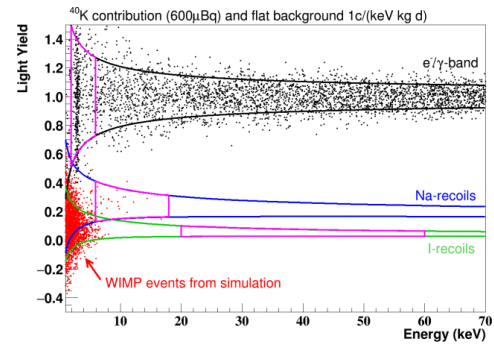


Figure 2. Simulated events for an exposure of 100kg days incl. e^-/γ -background (black) and DM signal (red). See text for details.

A subset of the authors recently published results of measurements of CsI [5], performed with a setup comparable to fig. 1. As both, CsI and NaI, belong to the family of alkali halides we are convinced that the experience gained with CsI allows a realistic estimate on the achievable performance of a COSINUS detector. Thereby, a distinct advantage of cryogenic detectors is a very low threshold for nuclear recoils: the design goal of COSINUS is a threshold of 1 keV.⁵

Fig. 2 shows a simulation for an exposure of 100 kg-days in the light yield - energy plane. The light yield is defined by the ratio of light to phonon signal. e^-/γ -events produce most light and, thus, get assigned a light yield of one. Nuclear recoils, instead, have lower light yields indicated by blue and green solid lines for Na and I, respectively.⁶ The black events correspond to the background budget reached by the DAMA experiment (flat background of 1 count/keV/kg/day + ^{40}K activity of 600 μBq). To illustrate the discrimination power of a COSINUS detector module we added a DM signal corresponding to the benchmark point shown in fig. 3 ($m=10$ GeV/ c^2 , $\sigma = 2 \cdot 10^{-4}$ pb). We want to stress that this signal reflects the standard scenario of DM particles scattering elastically and coherently off nuclei. The benchmark point was chosen in accordance with the interpretation of the DAMA signal in this scenario as put forward by the authors of [2].

As COSINUS detectors measure a phonon signal the threshold is (practically) identical for nuclear and electron recoils. However, for experiments like DAMA only measuring scintillation

⁴ For the first prototype (see fig. 1) we used a CdWO_4 carrier connected with silicon oil to the NaI-crystal.

⁵ Currently, the CRESST-II experiment, which is based on the same technology, has world-leading sensitivity for light DM achieved by a nuclear recoil threshold of 0.3 keV [6]. Furthermore, first prototype measurements indicate that the new CRESST-III detectors reach nuclear recoil thresholds well below 100 eV.

⁶ The bands for nuclear recoils off Na and I were calculated with the energy-dependent quenching factors of [7].

